ANOMALIES OF THE SPINE*

A CORRELATION OF ANATOMICAL, ROENTGENOLOGICAL, AND CLINICAL FINDINGS

By WILBUR BAILEY, M.D.
AND
RAY A. CARTER, M.D.
Los Angeles

DISCUSSION *by Paul E. McMaster, M. D., Los Angeles; Harold E. Crowe, M. D., Los Angeles.*

FROM an anatomical standpoint the spine is such an exceedingly complicated structure, and consists of so many individual parts, that one might almost expect to find abnormalities of development as the rule rather than the exception. As a matter of fact, as many as 67 per cent of spines do show some such variations.

Since abnormalities are so frequent and of so many varieties, it is of considerable importance, from a clinical standpoint, to know which types may be properly regarded as likely to produce symptoms, and which types may safely be considered as without clinical significance. Of equal interest is the fact that certain anomalies may present an appearance which must be differentiated from old or recent injury.

DEVELOPMENT

Since all anomalies are directly traceable to developmental errors, a brief recapitulation of this process is in order. This discussion may begin at the embryonic period in which the neural canal and notochord have formed, and the mesoderm is dividing transversely to form the somites. The mesoderm by this time has differentiated so that a mesodermal paraxial mass lies on each side of the neural canal and notochord. This structure will form the future spine. Guided by dorsal intersegmental arteries, the paraxial and adjacent mesodermal masses divide transversely into segmental blocks, or somites. The blocks so formed are called the scleratomes, and are the anlage of the vertebrae. Segments are laid down for the three fused vertebrae which form the occipital bone, as are seven cervical, twelve dorsal, five lumbar and five sacral, and eight to ten caudal vertebrae. The caudal segments later degenerate, three or four coccygeal segments remaining. Variations in the number of vertebrae arise at the stage of somite division, or later by variations in the number of caudal vertebrae which degenerate.

However, a vertebra is not developed within the somite. A change occurs by which sclerotomes of two adjacent somites participate in the formation of a vertebra, and by which it thus comes to be located opposite an intersegmental septum, rather than in the somite itself. Appreciation of this point is necessary to comprehend certain anomalies and to understand the relation of the vertebra, with its processes and ribs, to the muscular structures.

Each sclerotome divides transversely into a caudal dense, and a cranial looser portion. These separate and reunite with the adjacent portion of the neighboring sclerotome. In this process the intersegmental arteries, which originally lay between adjacent sclerotomes, now come to lie within them, as is shown diagrammatically in Fig. 1.

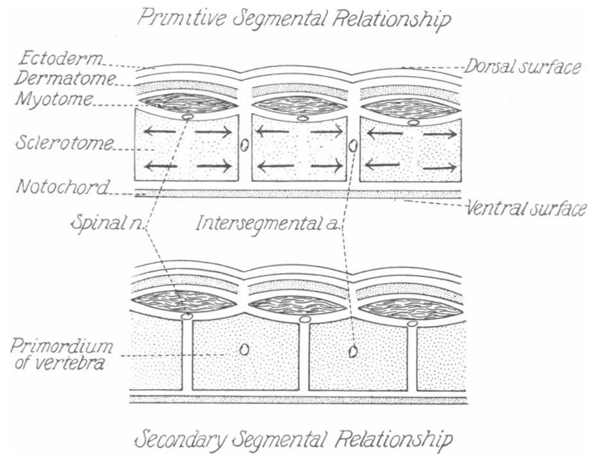

Fig. 1.—Fusion of adjacent halves of the sclerotome (as indicated by arrows), encloses the intersegmental artery within the future vertebra and brings the vertebral body opposite an intersegmental septum.

By growing to enfold the neural tube and notochord, the paired sclerotomes form the vertebrae. The neural or dorsal processes grow dorsally about the neural tube to form the neural arch. Paired medial processes enfold the notochord to become the body. Ventrolateral processes form from the costal processes. Secondary buds from the neural processes form the transverse and articular processes. Loose mesodermal tissue, not incorporated in the sclerotome, forms the intervertebral disc. The notochord in the center of the disc persists as the nucleus pulposus. Within the vertebral body it disappears. The costal processes, transverse processes, and ribs grow from the sclerotomes into the intersegmental septa, lying between adjacent somites.

The foregoing description concerns the membranous or blastemal stage of development. Varied deformities may be caused by injurious influences at this period. Nondevelopment of the neural bow will result in spina bifida. Inhibition of a ventral process will produce hemivertebra and absence of corresponding processes and ribs. Disturbances of the division, and recombination of the sclerotomes, may result in various irregularities, including unilateral supernumerary segments, or an alternation of segments in which hemivertebrae on one side lie opposite an intervertebral disc on the other. There may be associated fusion of ribs. The aberrations may be numerous and the pattern of development very disorderly. Gross deformity, particularly scoliosis, may be produced, or the multiple defects may compensate each other quite well, as in Fig. 2. More or less complete fusion of two or more vertebrae may occur. This may be related to the fact (Bardeen [1]) that at one period the mesodermal anlage of the intervertebral disc is very thin. (See Fig. 3.)

During the second, or chondrogenous stage of development, the original blastemal structures are transformed to cartilage. At this period the vertebral bows meet to complete the neural arch. Failure of development at this stage results in spina bifida.

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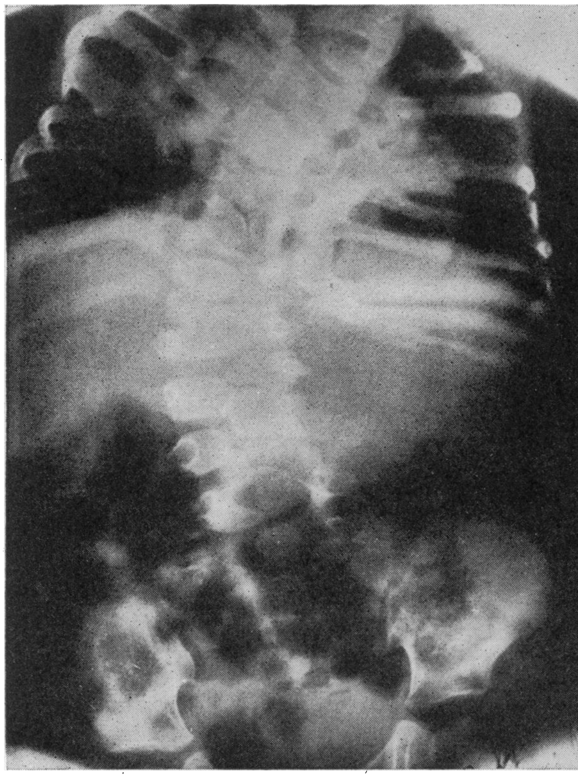

Fig. 2

Fig. 3

Fig. 2.—Infant spine showing multiple developmental abnormalities, including hemivertebrae, fused vertebrae, and divided vertebral bodies. (The latter result from failure of fusion of the two centers of ossification in the body.) Numerous rib anomalies are present.

Fig. 3.—Fused vertebrae. The third and fourth cervical vertebral bodies are fused together, only faint evidence of an intervertebral disc being present. The complete fusion of the spinous processes indicates a developmental etiology.

The third, or osseous, stage of development is initiated by the appearance of centers of ossification. One forms in each neural arch and two in the body. These latter normally fuse quickly, but may remain separate so that the body ossifies from two centers. We have one case (Fig. 2) in which these centers failed to fuse, the vertebral body remaining as two separate lateral halves. Similarly, one lateral half of a body may fail to ossify and, therefore, remain cartilaginous.

The neural arch of the fifth lumbar vertebra may ossify from two centers, the cartilaginous interval lying between the superior and inferior articular processes. This weakness may permit separation, allowing the body to slide forward without support, producing spondylolisthesis.

Nothing has been said about the chronology of these stages of development, since its details are not material to this presentation. The osseous phase begins about the seventh week and prolongs itself through adolescence, so that variations of it may occur until there is complete osseous maturity. The blastemal phase begins in the earliest weeks of pregnancy with the appearance of the sclerotomes. The chondrogenous phase begins in the sixth week, and the cartilaginous neural bow is complete in the fourth month. There is thus much overlapping of the stages of development.

FUSED VERTEBRAE AND HEMIVERTEBRAE

The development of these types of anomalies has just been considered. These defects may occur at any level. In the cervical region they may be present in combination with complete absence of some segments in the neck in the so-called Klippel-Feil syndrome. Hemivertebrae often produce a marked scoliosis. The diagnosis is easily made by a radiographic examination, and there is a general agreement that such a scoliosis may produce symptoms. With the exception of small supernumerary segments it is not likely that hemivertebrae would be mistaken for fracture, and the main interest, therefore, lies in the presumably weak anatomic structure which they cause.

Fused vertebrae may have an appearance suggesting an extinct disease process which has destroyed the intervertebral disc or an old injury. Often the normal stature of the bodies or the complete coalescence of some portion, such as the spinous process, as in Fig. 3, will make possible a differential diagnosis.

SPINA BIFIDA

Failure of fusion of the spinous processes is particularly common in the lumbar and sacral regions. Unless accompanied by an actual protrusion of the soft tissues, this finding is generally considered as not significant. Cushway and Maier[2] found 156 instances of spina bifida occulta in examining the backs of 916 supposedly normal men who were applying for railroad work, and we find the incidence equally high. We are in accord with the general agreement in the literature that there is no practical or theoretical reason why minor variations or actual failure of fusion of the spinous processes in this region should be productive of symptoms.

SPONDYLOLISTHESIS

As mentioned earlier, the primitive neural arch of the fifth lumbar vertebra occasionally ossifies in two centers instead of one. Under such circumstances, the cartilaginous interval or "isthmus" lies between the superior and inferior articular processes.

The vertebral bodies in the lumbar region are subjected to an unusual shearing stress because of their position at the weight-bearing lower end of the spine. This stress tends to make the bodies slip ventrally. Ordinarily this ventral movement is checked by the inferior articular and spinous processes. When the structure connecting these processes with the remainder of the body gives way, however, which may readily happen if it is only cartilaginous, spondylolisthesis may occur.

Out of thirty-eight cases picked at random from our material, in two the spondylolisthesis was between the fourth and fifth lumbar vertebrae instead of at the usual location, between the fifth lumbar and first sacral bodies. In these cases the separation at the "isthmus" was not so clearly seen. It is to be hoped, with the recent improvements in equipment, that six- and nine-foot lateral films will be possible. These should greatly reduce magnification and improve detail in the lumbosacral region.

TRANSITIONAL VERTEBRAE

The formation of the normal number of seven cervical, twelve thoracic, five lumbar, five sacral, and four coccygeal segments has been discussed. Variations from this formula occur in about 20 per cent of skeletons. At occipito-cervical, the cervicothoracic, thoracolumbar, and lumbosacral junction, the so-called transitional vertebrae occasionally appear, which share some of the characteristics of both groups.

The seventh cervical vertebra, for instance, may show ribs of varying lengths articulating with or, more usually, actually fused with its transverse processes. There is no doubt that cervical ribs, even when partly fibrous, may produce very definite symptoms in the upper extremities because of pressure on the brachial plexus. The great majority of the cervical ribs which come to our attention, however, are discovered as incidental findings, no symptoms referable to them being present. On the contrary, when cervical rib is suspected clinically, only in about one out of ten times is this anomaly actually found.

At the dorsolumbar junction, the twelfth dorsal vertebra may have such short ribs, or the first lumbar vertebra may have such well-developed ribs, that it will be hard to differentiate between the first lumbar and last thoracic vertebra. Under such circumstances, or when a similar question arises in the lumbosacral region, the differentiation can generally be made, when important, by examining the entire spine.

Lumbar ribs occur in about 10 per cent of spines, and sometimes cannot be distinguished from persistent epiphyses opposite the transverse processes. It is much more important, however, to differentiate these two anomalies from fracture than from each other. Any lumbar segments may show such anomalies.

The lumbosacral transitional vertebrae are characterized by the occurrence of enlarged transverse processes (the so-called costotransverse processes) on one or both sides. (See Fig. 4.)

These enlarged transverse processes may not be sufficiently large to reach either the sacrum or the ilium, but at times they articulate with the sacrum or even the ilium on one or both sides. Sometimes there is actually unilateral or bilateral fusion of these processes with the sacrum. In deciding whether large transverse processes are in contact with the sacrum, it must be remembered that the usual anteroposterior film of this region shows it at a considerable angle. If the angle of projection be changed by flexing the patient's thighs or changing the position of the tube, the effect of overlapping may disappear, and a definite space may be seen between the large transverse process and the sacrum.

If the twenty-fourth vertebra (normally the fifth lumbar) becomes united with the sacrum by bilateral bony union, the process of sacralization is complete. This may result in a six-piece sacrum. Conversely, complete lumbarization of what is normally the first sacral segment may occur—a finding which should result in a four-piece sacrum. Actually, a segment is often lost to, or borrowed from the coccyx, so that the sacrum maintains its usual quota of five pieces. By this means the actual level of transition from lumbar to sacral spine may be anywhere from the twenty-fourth to the twenty-sixth segment.

To what extent clinical symptoms are caused by lumbosacral transitional vertebrae is a much debated point. From a physiological aspect the lumbosacral articulation serves as the junction point between the rigidly fixed pelvis and the mobile lumbar spine. From the clinical aspect the frequent occurrence of low-back pain following comparatively mild trauma indicates that the lumbosacral region is a point of decreased resistance. The point of interest here is whether congenital anomalies represent additional factors of decreased resistance.

Complete lumbarization of the first sacral vertebra lengthens the lumbar spine to six segments, and therefore allows slightly increased mobility, which would, theoretically, make the spine structurally weaker. If there are two well-formed lumbosacral transverse articulations present, because of sacralization of the last lumbar vertebra, the lumbosacral junction may be strengthened, but periarthritic changes at these transverse anomalous articulations may occur, which are said to be productive of pain. Radiographically, sclerotic reactive changes are frequently found surrounding such anomalous articulations.

The incomplete and the unilateral types of enlarged costotransverse processes, many authors agree, are occasionally the cause of low-back pain and other symptoms. Those who, on the contrary, believe these anomalies cause no symptoms argue that they have been present from birth; yet symptoms do not develop until adult life, usually in the

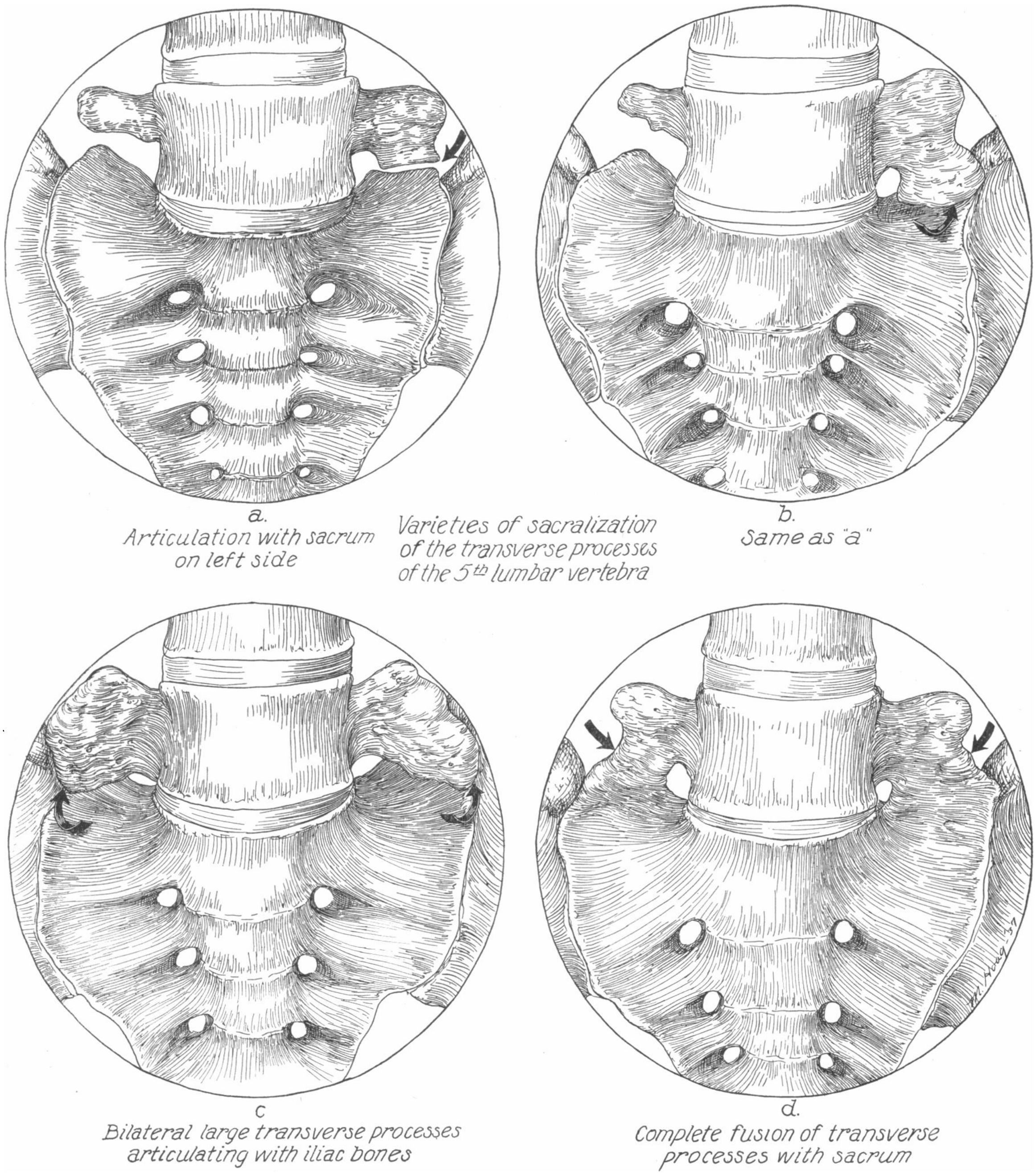

Fig. 4.—Types of lumbosacral transitional vertebrae.

third decade. Furthermore, during routine examination, the condition is found in many patients who have no symptoms. Opposing this viewpoint stand the arguments that in early life the process is mostly cartilaginous and, therefore, not likely to produce symptoms till ossified; that even though patients are found who are symptom-free, this anomaly may, nevertheless, indicate a point of weakened resistance; and that, from a mechanical standpoint, trouble might be expected. Such trouble would be caused by an enlarged process which, though not actually in contact with the sacrum, might impinge on it during lateral bending and thus nip the intervening soft tissues and periosteum.

A large unilateral process may serve as a fulcrum when motion is in its direction, so that abnormal stretching of the ligaments on the opposite side is caused. The arthritic changes (Mitchell)[3] which may be present around these anomalous joints not only produce pain themselves, but may be sufficient to involve the adjacent nerves by encroachment on the intravertebral foramina. In fact, Wagner[4] shows a number of cases in which referred pain in the lower extremities has been limited to the distribution of the lower lumbar and upper sacral nerves. He believes the cause to be directly traceable to various types of transitional lumbar vertebrae.

It seems likely that the question of whether these anomalies produce symptoms will continue to be disputed, and that the outlook of different authors will vary according to whether they have an industrial practice in which many cases of low-back

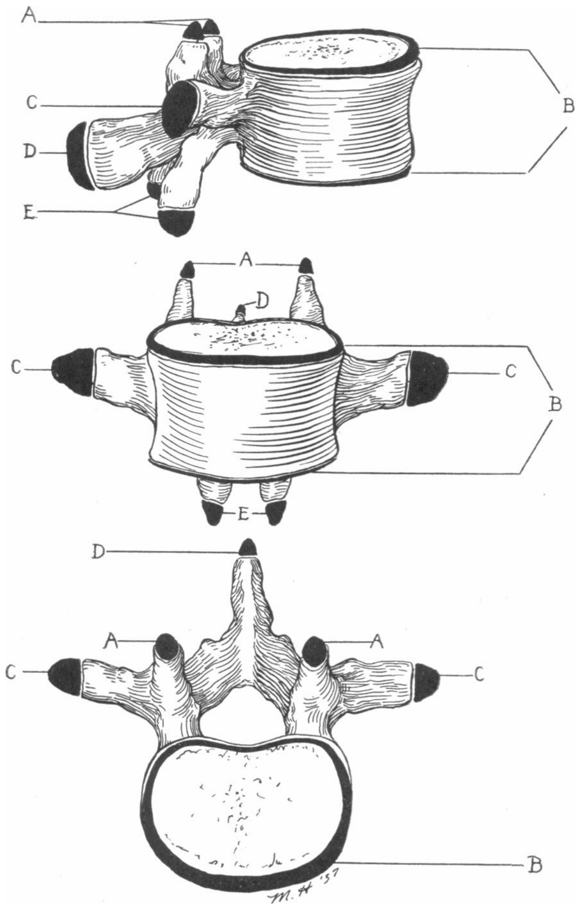

Fig. 5.—Possible locations of persistent epiphyses. (A) Superior articular processes. (B) Rim-like secondary epiphyses around vertebral body. (C) Transverse processes. (D) Spinous process. (E) Inferior articular processes.

pain are radiographed, or whether they note these anomalies incidentally in films made for examination of the urinary tract or some similar purpose.

Far more conclusive than much of the speculation which has appeared on the subject is the report of Bohart,[5] who made radiographic examinations of the entire spines of one thousand switchmen on the Belt Railway Company of Chicago. These switchmen have particularly hazardous work, which practically requires that they be trained athletes. In the year before routine examinations of the entire spine were instituted, there had been forty-seven back injuries. After the examinations were started, all persons with arthritic lipping or spur formation were not employed, but those with anatomical variations and anomalies were accepted, if the man was otherwise physically strong.

The results were astonishing. In the two and one-half years following the examinations there were only two litigations in cases of low-back pain in contrast to the forty-seven in a single year before such examinations were started. Since no anomalies of the spine had been weeded out, Bohart concludes that anomalies play no part in making men more susceptible to injury. In fact, his patients with cervical ribs were injured, but there were no complaints relative to their cervical ribs. Likewise, some of the men with spina bifida occulta

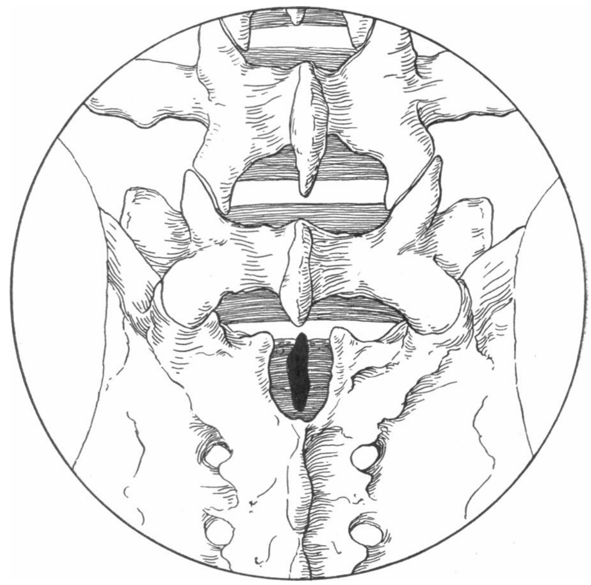

Fig. 6.—Persistent epiphysis of the spinous process of the first sacral segment. Fusion has not resulted because of a concomitant spina bifida.

and sacralized vertebrae had serious falls from the tops of freight cars moving at high speeds, but they had no complaints relative to their anomalies.

Our experience is in close accord with these findings. While we find marked osteo-arthrosis or obesity frequently associated with low-back pain, the incidence of lumbosacral transitional vertebrae is not appreciably higher in such cases than in films made for other purposes.

PERSISTENT VERTEBRAL PROCESS EPIPHYSES

While an absence or irregularity of primary centers of ossification will produce the defects just discussed, the secondary centers, or epiphyses, which frequently appear during the growth period opposite the tips of any of the vertebral processes, may fail to fuse at the usual time. The possible locations of these "persistent" epiphyses appear in Fig. 5. The ossicle which is thus formed is more than a pathological curiosity, for it may be wrongly interpreted as fracture.

Secondary epiphyses occur with regularity opposite the uppermost thoracic vertebra and, according to Gråberger,[6] a "persistent epiphysis" at this point is found in 0.7 per cent of all individuals. No diagnostic difficulties are experienced when this anomaly is bilateral, because the two sides are symmetrical. Unfortunately, from a diagnostic standpoint, unilaterality is the rule.

The spinous processes may also have small persistent ossicles opposite their tips in later life. The appearance of these epiphyses is especially strange when the spinous process has not fused properly (Spina bifida occulta), as frequently occurs with the first sacral vertebra. Under these conditions a small ossicle, about the size of the tip of a spinous process, is seen lying in the fissure between the ununited spinous process, as in Fig. 6. This ossicle is completely free from any of the surrounding bones, and is united only by soft tissue to the portions of the spinous process with which it would normally have fused completely. Persistent spinous process epiphyses are usually distinguishable from fracture by (1) their multiplicity, (2) their location at the tip of the process instead of at the mid-portion where the structure is weakest, and (3) by the points later to be described common to all of the process anomalies.

Similar unfused centers of ossification opposite the inferior articular processes of the lumbar vertebrae are not rare, while more seldom the superior articular processes show this phenomenon. In a previous communication,[7] the literature on this subject was reviewed, and emphasis laid on the necessity for differentiation from fracture. Unlike the transverse processes, however, isolated fractures occur in the articular processes only with rarity, and are not only disabling because of the amount of pain produced, but usually have a definite antecedent history of a sudden bending or rotating motion while the spine was locked in flexion or extension.

In general, the radiographic appearance of persistent epiphyses of the vertebral processes may be differentiated from fracture because:

1. The anomalies are often bilateral or multiple. Multiple fractures may occur, but lack regularity.
2. The margins of the persistent epiphyses have a sharp cortical outline, while a typical fracture line is serrated and small comminuted fragments may be present.
3. The epiphyses are often larger or show some irregularity of shape which would not be expected in a fracture fragment.
4. Fracture fragments are nearly always displaced by ligamentary or muscle pull, and do not appear in close apposition to their base with the bone cortices completely parallel, as is the case with the anomalies.

The rim-like secondary epiphyses occasionally fail to fuse, thus leaving a triangular piece of bone at the vertebral body margin.

They can be differentiated from fractures of the vertebral margins by (1) the separation between the epiphysis and body which is occupied by space-taking epiphyseal cartilage; (2) the lack of compression of the body; (3) the absence of "offset" of the fragment; and (4) the fact that the persistent epiphysis does not change position when the spine is flexed or extended, which is almost invariably the case with a fracture fragment not in contact with the vertebral body.

SUMMARY

An attempt has been made to correlate the anatomical, roentgen, and clinical findings in the more important developmental abnormalities of the spine in an effort to show how such abnormalities can be differentiated from fracture and from which a variety of symptoms may be expected.

2007 Wilshire Boulevard.
General Hospital of Los Angeles County.

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DISCUSSION

Paul E. McMaster, M.D. (1930 Wilshire Boulevard, Los Angeles).—The authors have discussed some important and practical points from a clinical and diagnostic standpoint. These are particularly pertinent in attempting to correlate the importance of anomalous lesions of the spine with certain symptoms. One of the features, as was pointed out, is the need to determine what effect or relationship, if any, such lesions might have to injuries, and especially those with an associated compensation factor. Quite frequently an examiner is called upon to estimate disability of spinal injuries in which cases roentgenograms reveal anomalies. Are these causative of the symptoms? Are they producing a prolongation of symptoms? The authors called attention to the fact that many of these lesions without symptoms are discovered, incidentally, to routine examinations. Thus, care should be exercised against indiscriminately attributing symptoms to an anomalous condition in the spine, unless other pathological conditions are ruled out first.

Congenitally fused vertebrae cause, as a rule, no significant symptoms. Hemivertebrae often give rise to scoliosis, which may be well compensated and without symptoms. Attempts have been made to remove these with variable success, due probably to technical difficulties. A spinal fusion would appear to be more feasible in the presence of symptoms.

Simple spina bifida occulta without herniation is not uncommonly encountered, and usually causes no symptoms.

Spondylolisthesis results from a congenital maldevelopment and frequently may produce low-back pain with an associated sciatic distribution often appearing after either a single severe or repeated minor injuries. Although an injury may be contributory in precepitating these symptoms, it is problematical as to how much importance an examiner is to place on the injury and how much on the congenital malformation, particularly in those cases with a compensation factor.

Transitional vertebrae are quite often the sites of anomalous development and, although a number of these may remain "quiescent," some, such as cervical ribs and others as abnormal transverse processes of fifth lumbar vertebrae fusing or articulating with sacrum or ilium, or both, are important in causing symptoms which at times are severe. Stereoscopic as well as oblique roentgenograms of the lumbosacral region are at times advisable, and may show an existent gap where, on routine anteroposterior views, a fusion or articulation of fifth lumbar transverse process to sacrum or ilium seemed to be present. Surgery usually offers relief in these cases.

Harold E. Crowe, M.D. (2417 South Hope Street, Los Angeles).—It is very frequent that areas of abnormal mobility, especially in the low-back region, will not only produce symptoms but produce changes in the bone which can be visualized by x-ray; and when these areas are seen at surgery during spinal fusion operations the abnormal motion and the sclerosing changes in the bone may be grossly visible. However, the problem of low-back conditions, like all other medical problems, is prone to be subject to waves of enthusiasm, and at the present time the tendency is to feel that the actual seat of pain in low-back conditions is in the soft tissue structures, especially ligaments and fascia associated with the skeletal low back. Since undue tension on ligamentous structures over a period of time will produce symptoms, the study of the statics of the low-back becomes just as important as the study of the bony structure on the discovery of bone disease.

X-rays taken in the standing position, while they are often not adequate to give actual bone detail, will very frequently explain the symptoms in these cases and lead to remedial measures which produce complete relief, simply through the change of the habitual stance of the patient. Where such postural faults are found associated with skeletal anomalies, it is undoubtedly true that the symptoms are aggravated by the skeletal weakness and the two findings may work together in producing the chronic pain.

As the study of the problem of pain of this sort grows more extensive, it becomes more and more obvious that there must be many explanations of backache and that no examination is complete which overlooks the numerous possible factors in any individual case, among which the points brought out by Doctors Bailey and Carter are of extreme importance.

THE LURE OF MEDICAL HISTORY†

PURKINJE'S PIONEER SELF-EXPERIMENTS IN PSYCHOPHARMACOLOGY*

By P. J. Hanzlik, M.D.
San Francisco

PART I

INTRODUCTION

If we agree with George Eliot that "Genius is an immense capacity for taking pains," then this definition exempts that immortal of biology and medicine whose work I propose to discuss tonight. Impatient with infinitesimal detail, intolerant of triviality, extraordinarily original, masterful interpreter of natural phenomena, unusually apt in spotting the right thing at the right time, pacemaker of experimental physiology, medicine and psychology—that was Johann Evangelista Purkinje, the scientist. Endowed with a vivid imagination, a keen philosophical mind, a prophetic vision, a tolerant spirit, a sympathetic nature, and a clear understanding of human affairs, and a man with the highest ideals who led a full and beautiful life—that was Purkinje, the man, the humanitarian, and the statesman. He was indeed unusually talented and remarkably ingenious, especially in the biological sciences.

Yet, in a recent paper (1933) on the history of physiology and physiologists, by an American physiologist,[1] Purkinje's name is barely mentioned. Purkinje is only alluded to as a contemporary with Liebig and Bunsen, as being the first to establish laboratories in anything like the modern sense. Purkinje is credited with some influence on Ludwig, who is suspected of having been affected, in planning his laboratory, by the example of Purkinje and these two noted chemists. So it is with many other physiologists—that Purkinje's name seems all but forgotten. His multitudinous activities have all but faded from the memories of scientists. Nevertheless. Purkinje was the pioneer of all modern physiology as it has developed to the present time. He was the forerunner of all great physiologists of modern times. For he antedated practically all the great experimental physiologists. To mention only a few: "Johannes Müller was just developing; Claude Bernard was six years old; Brown-Séquard and Carl Ludwig were infants; Brücke was uttering his first cry; Helmholtz and Huxley were yet unborn, when Purkinje published his thesis in 1819" (Robinson).[2] He preceded, by seventy years, Francis Galton in making use of finger-print identification; in fact, first proposed the idea scientifically. He established at Breslau, in 1839, the first laboratory of experimental physiology in Germany, and only Magendie had made previously a similar effort, in France. He originated the first course in experimental physiology in Breslau in 1824. He created, in 1850, at the age of sixty-three, another institute of physiology in Prague. Probably his best-known pupils were Valentin, Pappenheim, Czermak, Sachs, Gregr, and Fritsch. He found physiology a speculative subject and left it an experimental science.

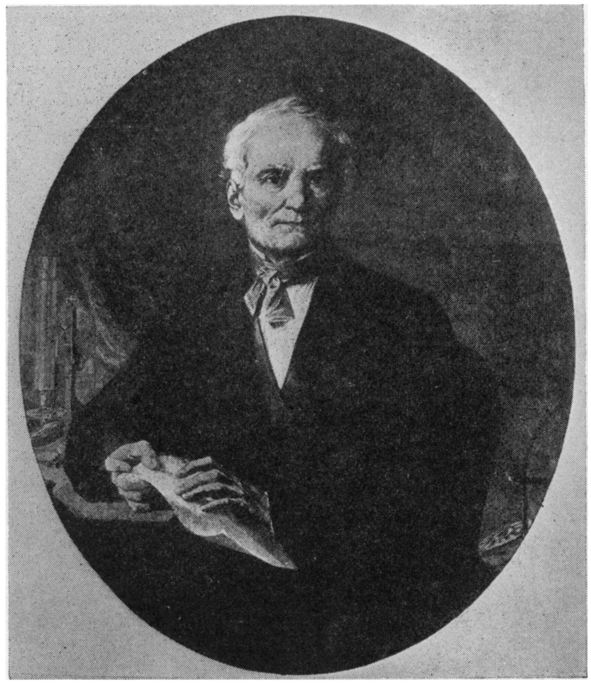

Fig. 1.—Johann Evangelista Purkinje (1787-1869). Oil painting by Maixner.

If some physiologists are to be called the masters of physiology, it would seem appropriate to speak of Purkinje as a supermaster (Figure 1). Therefore, one reason why I propose to discuss Purkinje is that he is an undeservedly forgotten experimental physiologist. Another reason is that he is even more obscure as a pharmacologist, although he made some remarkably original experiments on himself which have never been discussed. Before considering these self-experiments, I may summarize his qualifications as an experimental biologist by citing his discoveries and achievements in biology and medicine, even at the risk of repeating some things which may be known.

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† A Twenty-Five Years Ago column, made up of excerpts from the official journal of the California Medical Association of twenty-five years ago, is printed in each issue of California and Western Medicine. The column is one of the regular features of the Miscellany department, and its page number will be found on the front cover.

* Sigma Xi address, University of Nebraska, Lincoln, Nebraska, February 16, 1938.

From the Department of Pharmacology, Stanford University School of Medicine, San Francisco.

References will appear in Part II.